CCUS: 4186372

Discussing Demigration Uncertainties Applied to Active Focused Seismic Monitoring

Baptiste Penot*[1], Bruce Webb[2], Michele Buia[3], Gianluca Dell'Elce[4] 1. SpotLight, 2. ENI.

This paper was prepared for presentation at the Carbon Capture, Utilization, and Storage conference held in Houston, TX, 03-05 March.

Abstract

A crucial aspect of CCS project development is the Measurement, Monitoring, and Verification (MMV) Plan, which requires cost-effective, frugal, and frequent monitoring tools. This paper discusses the reliability of spot seismic as a surveillance tool for CCS projects, based on a real offshore UK seismic imaging dataset. The initial knowledge of the wavefield allows for locating specific sub-surface positions referred to as spots using legacy acquisition designs, also called de-migration. It uses migrated seismic data, coupled with uncertainties that must be addressed to mitigate risks linked to the spot seismic solution. By analyzing spot positions through a sensitivity analysis on velocity models, new crucial considerations regarding (de-)migration uncertainties applied to focused seismic reflection monitoring are highlighted. This study relies on the use of a ray-tracing based de-migration algorithms on different perturbed propagation models built using a velocity model and its associated standard deviation. A sensitivity analysis is then conducted, enabling the qualification and quantification of spot positioning variability. The latter ultimately influences decisions about the reliability of these positions in the subsurface and potentially triggers the computation of alternative spots with reduced uncertainty. Two spots exhibiting opposite behavior are chosen and compared leading to two main conclusions: first, the higher frequency of the target horizon, the more non-linear the spot positioning become for a given antenna; second, velocity perturbation have a lesser impact on the same output. While the position of monitored spots in depth is quite simple to determine with simple geology frameworks, the model propagation can be more challenging with complex geology frameworks and highly variable velocity models. The impact of the non-uniqueness of models generated by migration can therefore become quite high, and thus uncertainties need to be handled with care and propagated at each step of the processing. This study utilizes velocity model uncertainties to evaluate spot positioning variability for the first time in a sensitivity analysis. By qualifying model uncertainties, the reliability of the spot seismic is significantly increased. Processing existing seismic data to design lighter monitoring tools such as the spot seismic for MMV is a critical approach and vision that leads the way for innovative seismic solutions.

Introduction

A crucial aspect of Carbon Capture and Storage (CCS) project development is the Measurement, Monitoring, and Verification (MMV) plan, which requires cost-effective, frugal, and frequent monitoring tools. This paper discusses the reliability of spot seismic as a surveillance tool for CCS projects, based on a real offshore UK seismic imaging dataset. Using a source and a receiver one can identify a reflection position or spot, on a target interface. Finding such triplet goes through the demigration process that uses among others, velocity models. Such models are however subject to uncertainties generated during the migration process. In this real case study, velocity model impacts on the demigration process are discussed. By qualifying model uncertainties, the reliability of the spot seismic is significantly increased. This provides an indirect, light, and cost-effective monitoring solution for CCS projects. Further explanations and way forwards are then provided to enhance the uncertainty workflow.

Theory

For this study, spots positions are identified by propagating a wave using the high frequency assumptions of the raytracing theory (Cerveny, 2000). The process requires a smooth model and interface to work properly. Using an original (V_0) and a standard deviation (σ) model, one can create a given number of perturbated propagation volumes (V_{σ_k}) by using the following rule:

$$V_{\sigma_k}(x,y,z) = V_0(x,y,z) + k * f(\sigma(x,y,z))\ \forall k \in [-3,3]$$

Merging models is allowed since V_0 and σ are both homogeneous to a velocity in meter per second.
Velocity and standard deviation models both exhibit multimodal shapes (cf. Figure 1) explained by dominant values (dominant geology for the velocity model; error patches on the standard deviation model). It should be noted that raytracing based approaches are very sensitive to any change in the propagation medium since the process is highly non-linear (Cerveny, 2000) and uses local model values. Therefore, changing a velocity model or a horizon depth is expected to output scattered results. As a consequence, the standard deviation models must be smoothed using a function $f: \mathbb{R}^3 \rightarrow \mathbb{R}^3$ such as a gaussian filter, spreading the modes of the statistical distribution.

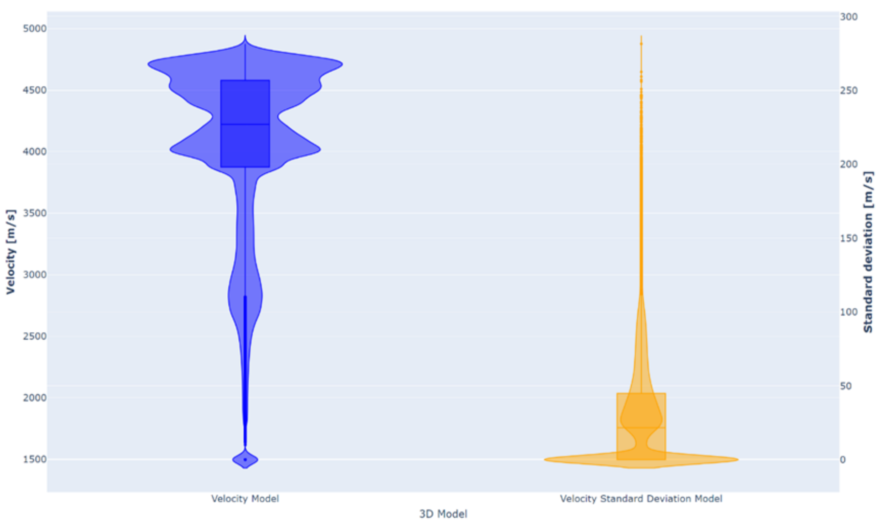

Figure 1: Statistical distribution of the velocity model values (left) and standard deviation values (right). Statistics are computed on the whole volume independently from the dimensions. Both distributions exhibit multimodal trends. Velocity model shows mainly

Running the same process on each perturbated model allows to derive multiple uncertainty levels. It is unfortunately not possible to use the normal law confidence intervals since the data is neither expected to have a normal distribution nor to be assimilated to it using the central limit theorem because of the dependence of the variables. In order to simplify the study, two spots have been chosen. Spot 1 is located on a sub-horizontal part of the top horizon, whereas spot 5 is in a chaotic part of the latter (cf. Figure 2, Figure 3).

Results

Demigration can be run using the same source-receiver couple for each model perturbation value (k). Reflection points on the top of the chosen formation can then be compared, first in a map plot, and then as distances to the spot found using the original velocity model (Figure 2).
Figure 2 highlights very different behaviors. Whereas Spot 1 has a sub-linear trend, Spot 5 has a chaotic repartition of the spots, as underlined by their regression coefficients. Perturbated spot 1 gives results within the 10 m range while spot 5 stays in the 70 m range with rays finding solutions up to 270 m. Such variability is well explained by: slopes of target horizon ; standard deviation patches and non-uniqueness of the demigration process (Cerveny, 2000). Given a fluid simulation cell size of 50 m, spot position is likely to stay inside the cell with low model and horizon uncertainty ; and in the 5 cells for highly perturbated areas.
Figure 2 and Figure 3 expresses the multi-factor nature of the demigration uncertainties. Two facts however stand out: the higher frequency the target horizon, the more non-linear the spot positioning ; velocity perturbation have a lesser impact on these outputs.
Chosen horizon complexity challenges the project, with considerable slopes and spikes. Going into the same direction, the velocity model shows high gradients with velocities greater than 4000 m/s at 900 meters depth. These are favorable to diving waves, which one does not want for focused seismic reflection.

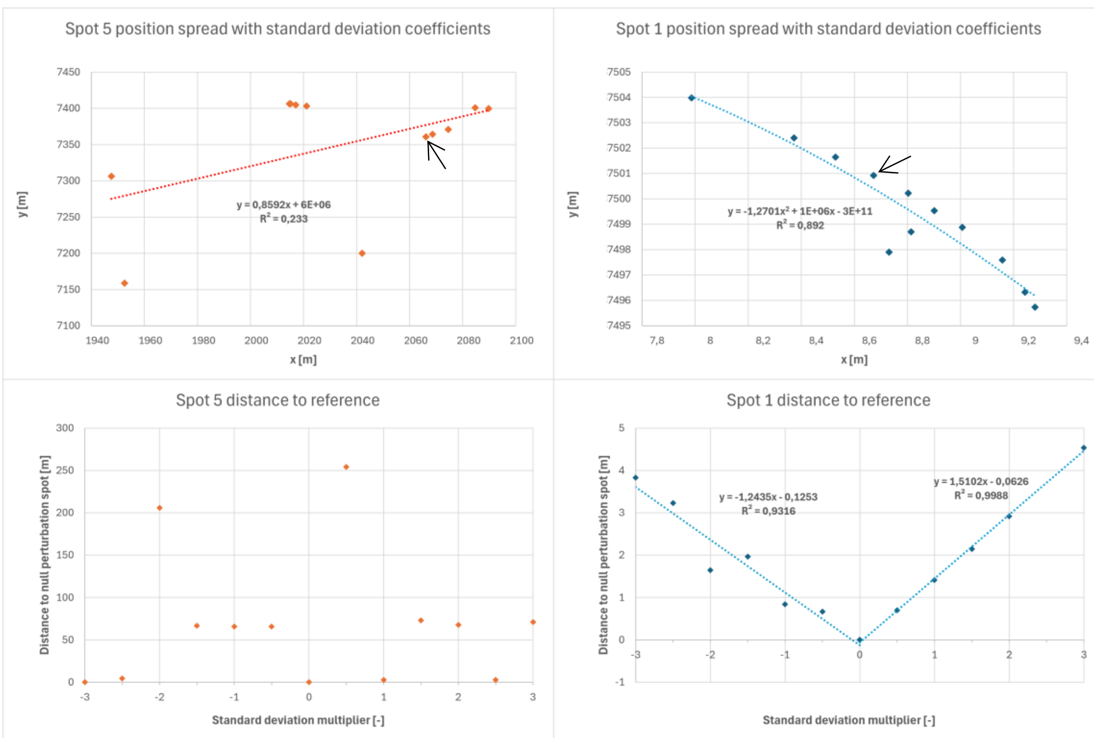

Figure 2: Top: XY maps of the spots showing the dispersion of the positions independently from the perturbation coefficient. Black arrows identifies the position of the reference spot. Whereas there is no clear trend on spot 5, spot 1 clearly shows a sub-linear trend, indicating some kind of linearity in the demigration process, therefore suggesting locally simpler models. Bottom: Euclidian distance to the default spot position (null perturbation) with respect to the perturbation coefficient. Whereas spot 5 does not provide a clear correlation between perturbation and distance to reference, spot 1 does, in a symmetrical linear trend (high regression coefficients).

Discussion

To complement this study, depth demigrations could be handled in a different way. Instead of using ray tracing (infinite frequency), one could run demigration with full wave or modeling algorithms (finite frequencies). Note that demigration is a hybrid process. It is made of a direct problem resolution: the propagation of the ray into the medium; as well as an inversion procedure generating non-unique results.

While ray tracing eases drastically the inversion, it struggles with geologies; wave propagation approaches have the exact opposite behavior. An hybrid method could also be used.

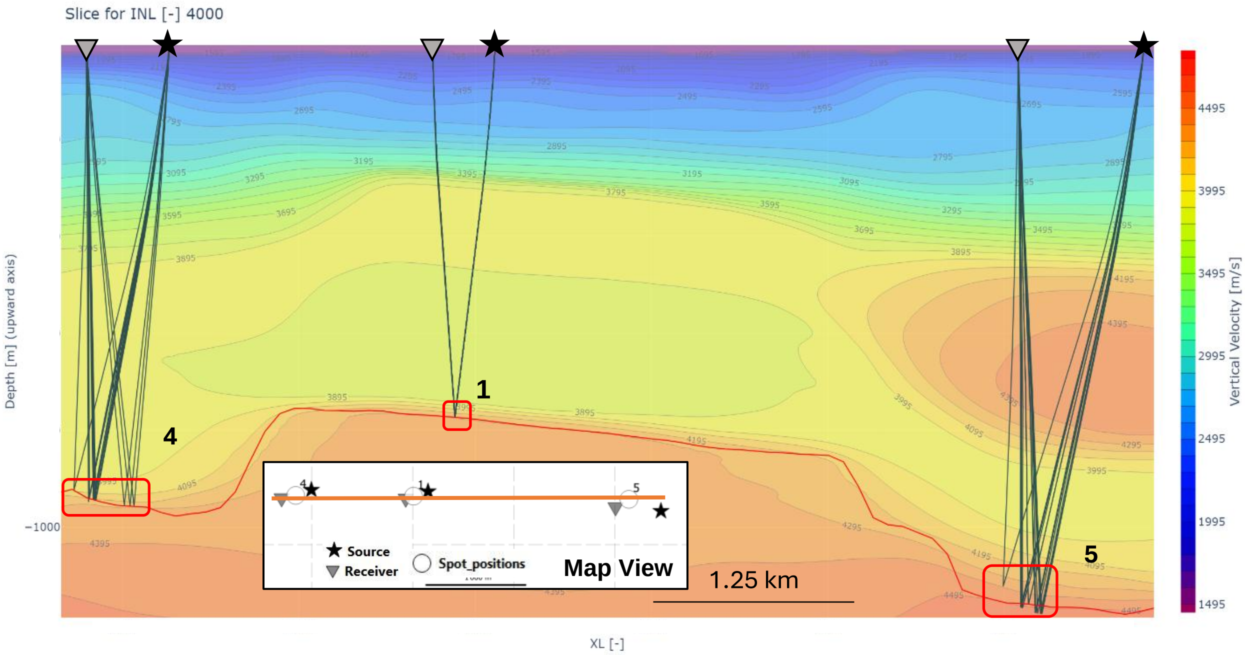

Figure 3: Projected ray paths (dark grey lines) associated to the different perturbations propagated in the original velocity model with the chosen horizon (red line); projected on a common inline. Spot numbers are writen in black. Red boxes highlights spots spreading. Integrated map of the offshore UK field shows sources, receivers, spots and cross-section trace. Rays are plotted independently from the perturbation coefficient. Spot 1 is very consistent in positioning and validates the former observations. Spot 5 is more chaotic with strong lateral variability suggesting that rays goes through more perturbated velocites. Same observations can be made for Spot 4. Note that the slice projection is responsible for making some spots not belong to the interface.

Furthermore, both algorithms and data are responsible for the nature of the result. Models and migrated stacks are generated using migration. Horizons are retrieved from the migrated volume using picking and are thus bonded to the migration algorithm. Knowing that full wave and migration methods can output different valid models based on the parametrization and the convergence (local or global minima), a comprehensive uncertainty study could consider the migration type. Effect of the migration on the demigration can be further studied using different algorithms on both sides.

Conclusions

Assessing the reliability of the monitoring solutions used in the MMV plans of CCS projects goes through identifying and estimating uncertainties linked to both acquisition and processing. While the position of monitored spots in depth is quite simple to determine with simple geology frameworks, the model propagation can be more challenging with complex geology frameworks and highly variable velocity models. In these cases, the impact of the non-uniqueness of models generated by migration can become quite high, and thus uncertainties need to be handled with care and propagated at each step of the processing. This study utilizes a real offshore UK dataset to evaluate spot positioning variability for the first time in a sensitivity analysis. By qualifying positioning uncertainties, the reliability of the spot seismic is significantly increased on the studied offshore field. Further decisions can now be taken regarding the known variabilities. To sum up, processing existing seismic data to design lighter monitoring tools such as the spot seismic for MMV is a critical approach and vision that leads the way for innovative seismic solutions.

References

Cerveny, V., 2000. Seismic Ray Theory. Department of Geophysics Faculty of Mathematics and Physics Charles University.

Filippo, V.D., Barton, C., Basu, P., 2024. Comprehensive Measurement, Monitoring, Verification Planning Enables Safe CO2 Storage, Risk Reduction, and Operating Cost Optimisation. First Break 42, 79–85. https://doi.org/10.3997/1365-2397.fb2024035

Mishra, P., Pandey, C., Singh, U., Gupta, A., Sahu, C., Keshri, A., 2019. Descriptive statistics and normality tests for statistical data. Ann. Card. Anaesth. 22, 67. https://doi.org/10.4103/aca.ACA_157_18

Pacala, S., Socolow, R., 2004. Stabilization Wedges: Solving the Climate Problem for the Next 50 Years with Current Technologies. Science 305, 968–972. https://doi.org/10.1126/science.1100103

Ringrose, P.S., 2017. Principles of sustainability and physics as a basis for the low-carbon energy transition. Pet. Geosci. 23, 287–297. https://doi.org/10.1144/petgeo2016-060